ESTCP
Cost and Performance Report

(CP-9707)

Venturi/Vortex Scrubber and Pushed Liquid Recirculation System for Controlling/Recycling Chromium Electroplating Emissions

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LIST OF ACRONYMS

CERL	U.S. Army Construction Engineering Research Laboratories
CPVC	Chlorinated Polyvinyl Chloride
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
In.	Inch
MCLB	Marine Corps Logistics Base
NESHAP	National Emission Standard for Hazardous Air Pollutants
NFESC	Naval Facilities Engineering Service Center
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
PLRS	Pushed Liquid Recirculation System
Scfm/sf	Standard Cubic Feet per Minute per Square Foot
SIBS	Spark-Induced Breakdown Spectroscopy
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USEPA	U.S. Environmental Protection Agency
VVST	Venturi/Vortex Scrubber Technology

ACKNOWLEDGMENTS

Dr. K. James Hay of the Industrial Operations Division of U. S. Army Construction Engineering Laboratories (CERL) managed this project and prepared the ESTCP documentation related to this project including this report. Dr. Shaoying Qi, an in-house contractor with CERL, and Dr. Hay performed the development work on the Phase III Venturi/Vortex Scrubber Technology and the Pushed Liquid Recirculation System. Dr. Norman Helgeson and Mr. Bruce Holden of NFESC contributed to all activities of the demonstration, particularly the coordination and planning. Benet Laboratory was responsible for the installation of both demonstrated technologies. The demonstration site was the U.S. Marine Corps Logistics Base in Albany, Georgia. The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) provided sampling and laboratory analysis. Other contributors include Physical Sciences, Inc., Watervliet Arsenal, and the U.S. Army Environmental Center.

Points of Contact can be found in Appendix A.

Technical material contained in this report has been approved for public release.

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1.0 EXECUTIVE SUMMARY

This Environmental Security Technology Certification Program (ESTCP) project demonstrated control technology for chromium air emissions. Chromium electroplating is an essential process for the U.S. Department of Defense (DoD) because chromium provides a surface coating with a combination of properties that are very difficult to substitute on military hardware. Unfortunately, the process is highly inefficient and byproduct gases rise as bubbles and burst at the surface to create an airborne mist of chromic acid particulates/droplets. Hexavalent chromium is a known carcinogen and these emissions are strongly regulated. The Venturi/Vortex Scrubber Technology (VVST) was the first air pollution control option developed under this project. The VSST was designed to collect the bubbles before they burst by recycling electroplating fluid through a unit that subjects the fluid to changes in flow direction to coalesce and separate the entrained gases. This technology was to be demonstrated and validated at two military industrial installations. However, the VVST failed during the initial trial. A second technology, the Pushed Liquid Recirculation System (PLRS) emerged through major program and design changes. The PLRS employs jets placed just below the liquid surface in the electroplating bath to induce a surface flow pattern which pushes the bubbles towards the ventilation hood at one side of the tank thereby reducing the effective tank surface area that requires ventilation by conventional control devices. This system is not an alternative control option but rather an additional unit that reduces the flow rate requirements of conventional ventilation systems. The PLRS was demonstrated, by modifying an active electroplating bath at only one site, the Marine Corps Logistics Base (MCLB) in Albany, Georgia.

The results of the demonstration showed that the PLRS successfully reduced the ventilation flow rate at MCLB Albany down to 75 scfm/sf, which is 63 percent of the existing ventilation rate and 70 percent of the original design flow rate. A reduction of emissions released directly above the center of the tank was also observed. Worker occupational exposure was maintained below the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 0.052 mg/m^3. This ventilation reduction translated to an estimated 25% reduction in capital costs (realized when the existing system requires replacement at the end of its normal lifetime) and a 48% savings in annual expenditures. The savings for a ten-year life cycle were estimated to be 38%. The potential life cycle savings due to PLRS implementation at the 21 DoD facilities and approximately 1,500 commercial shops that conduct hexavalent chromium electroplating and/or anodizing operations is estimated to be over $100,000,000. This assumes that each commercial facility has two average sized tanks and the average life cycle cost per tank for conventional technology is $90,000.

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2.0 TECHNOLOGY DESCRIPTION

The Venturi/Vortex Scrubber Technology (VVST) recycles electroplating fluid through a unit that subjects the fluid to changes in flow direction to coalesce and separate entrained gases. Thus, rising byproduct gas bubbles are collected before they burst

However, the VVST concept was abandoned during this demonstration due to insurmountable design flaws and was replaced with the Pushed Liquid Recirculation System (PLRS). Descriptions of the three design versions of the VVST can be found in the VVST development report (Hay et al., 1998b). The reasons for the switch to the PLRS from the VVST are given in the final ESTCP technical report for this demonstration (Hay et al., 1999).

The basic principle behind the PLRS is to control bubbles of byproduct gases generated during the active plating with a surface flow that pushes them towards a ventilation duct where they are collected from a small surface area of the tank. Electroplating solution is recirculated by a pump from the side with the ventilation hood and back to the tank through liquid jets on the opposite side facing the hood. The flow out through these jets provides an even cross-flow across the surface to the far wall of the tank. A conventional pull control device is still required, although smaller in size, due to the reduced ventilation requirements for the electroplating tank.

In contrast to the VVST concept, the PLRS does not have the added benefit of recycling chromium air emissions directly back into the solution. However, most newer control devices allow for a closed-loop scrubber rinsewater system by including a first-stage pad near the plating tank to collect the majority of captured chromium emissions. The pad is then periodically rinsed with deionized water, which is drained back into the electroplating tank. The addition of scrubber rinsewater is usually overcompensated by the evaporated losses from the hot electroplating tank.

Operation of the PLRS unit is simple and requires no additional labor. The system power should be linked to the rectifier so that the pump operates during active plating. Operator training requirements are minimal.

The primary strength of the PLRS is that, by reducing the required ventilation rate, a lower life-cycle cost can be realized. The advantages of this technology over conventional end-of-pipe control technologies include:

- Lower capital cost (smaller ventilation system needed);
- Reduced scrubber wastewater (less water needed for washing down smaller system);
- Minimized space requirements for treatment device and ventilation ducts;
- Replaces conventional air circulation for the plating tank (conventional air circulation contributes to emission generation);
- Lower energy costs; and
- Removal of less climatized air from plating shop (additional energy savings).

Disadvantages associated with this technology include:

- Use of some space in the plating tank - several inches near the long sides of the tank for the liquid piping (this space requirement may be problematic for crowded tanks)
- Higher chromium loading in ventilation air
- Less significant cost savings for facilities running 24 hours per day, due to the energy requirements of the liquid pump.

There are also other competing ideas available for reducing ventilation requirements, such as sealed tank covers, automated tank covers, push-pull air systems, and mist suppressants.

The idea of tank covers is not well accepted by plating shops in DoD. Covers do not allow for convenient placement and withdrawal of parts, particularly when multiple parts are processed simultaneously.

Push-pull air systems allow for a decrease in ventilation by pushing the emitted mist particulates/droplets with an air jet across the top of the tank towards the ventilation hood. This is a very similar concept to that of the PLRS, except the PLRS pushes the liquid and suppresses the generation of the emissions until they are below the hood. Push-pull air systems can be effective if designed properly. However, achieving the proper design can be difficult and obstacles in the air path can easily disturb a push-pull system's effectiveness. The expected ventilation reduction (for a well designed system) can be almost as large as that of the PLRS.

The potential benefits of mist suppressants could be impressive. As part of the National Emission Standard for Hazardous Air Pollutants (NESHAP), decorative chromium electroplating and chromic acid anodizing shops can meet compliance by using only fume suppressants (i.e. no control device). This would incur material costs of approximately $600 per tank per year with potentially no capital costs. Mist suppressants typically contain fluorinated agents that reduce the surface tension of the bath so that gas bubbles do not burst with the energy necessary to propel liquid particulates/droplets into the air above the tank. The concentration of chromium directly above the tank can be reduced by as much as 98% (Ferguson, 1998). Unfortunately, mist suppressants chemically alter the plating solution chemistry and have been suspected of adversely affecting plating quality, particularly for hard chromium electroplating where the plate is very thick. Since all DoD facilities perform hard chromium electroplating for durability, strength, reliability, and wear, the use of mist suppressants is completely avoided.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

The original goal of this project was to demonstrate the VVST at the Marine Corps Logistics Base (MCLB) in Albany, GA and at Hill Air Force Base in Ogden, UT. The primary objective was to demonstrate that this device could replace conventional technology and meet applicable air emission regulations. However, because of the design flaws of the VVST technology, these performance objectives became unrealistic, and the focus of the demonstration was switched to the PLRS.

The demonstration objectives were changed for the PLRS because it does not replace the need for a conventional ventilation/control system, but rather minimizes the ventilation rate and equipment size. The PLRS was demonstrated at MCLB, Albany, GA. The second planned demonstration at Hill Air Force Base was canceled. The new objective of the demonstration was to evaluate the ability of the PLRS to control chromium electroplating air emissions below applicable regulatory standards in an economically advantageous manner by reducing ventilation requirements. The standard to be met for DoD acceptance was the OSHA PEL requirement of 0.052 mg/cm^3 chromium air concentration in the workspace (29CFR1910.94). There has been discussion of a possible, more stringent OSHA standard (0.5 micrograms per cubic meter on a 8 hour time-weighted average), which would be two orders of magnitude less than the current standard (Altmayer, 1996). If adopted, this would be a difficult standard to meet. Although not necessary for compliance, this possible standard served as a benchmark for this demonstration. This technology was also expected to reduce the costs of conventional technology without disrupting standard plating operations and plating quality control.

3.2 PHYSICAL SETUP AND OPERATION

Figures 1 and 2 show the positioning of the PLRS in T-60 at MCLB Albany. In the demonstration, the liquid was pulled off the plating tank (T-60) through a 2-in. diameter chlorinated polyvinyl chloride (CPVC) horizontal withdraw pipe placed approximately 6 in. below the surface on the southwest side of the tank. There were 3/8 -in. holes (3-in. spacing) in this withdraw pipe facing the southwest tank wall (rear wall) pointed 45 degrees upward. The liquid was pumped through 2-in. diameter CPVC piping by a 7.5 horsepower centrifugal pump. The flow passed through a throttle valve and an inline flow meter so that the flow rate could be controlled and monitored. The liquid was pumped back into the tank through two horizontal discharge pipes with ¼-in. diameter holes placed at approximately 1.5 in. below the surface. The holes were evenly spaced (1.5 in.) across the front of the pipes and directed towards the opposite tank wall at a slight upward angle (15 degrees).

Bubbles were collected at the southwest wall of the tank under the modified ventilation hood. This modification consisted of a CPVC sheet with a 90-degree angle placed at the air inlet that extended the effective air intake farther out into the tank and closer to the surface to capture the bubbles that popped under the extension and minimize their ability to escape. The modification extended 3 in. outward and allowed an approximate 12-in. gap to the liquid surface.

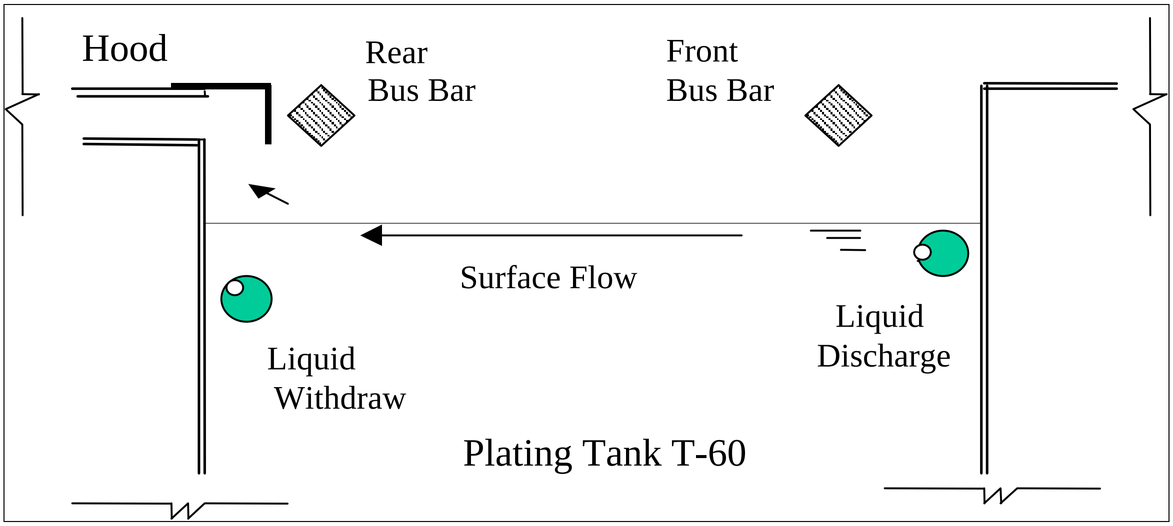

Figure 1. Cross-Section View of PLRS (not to scale)

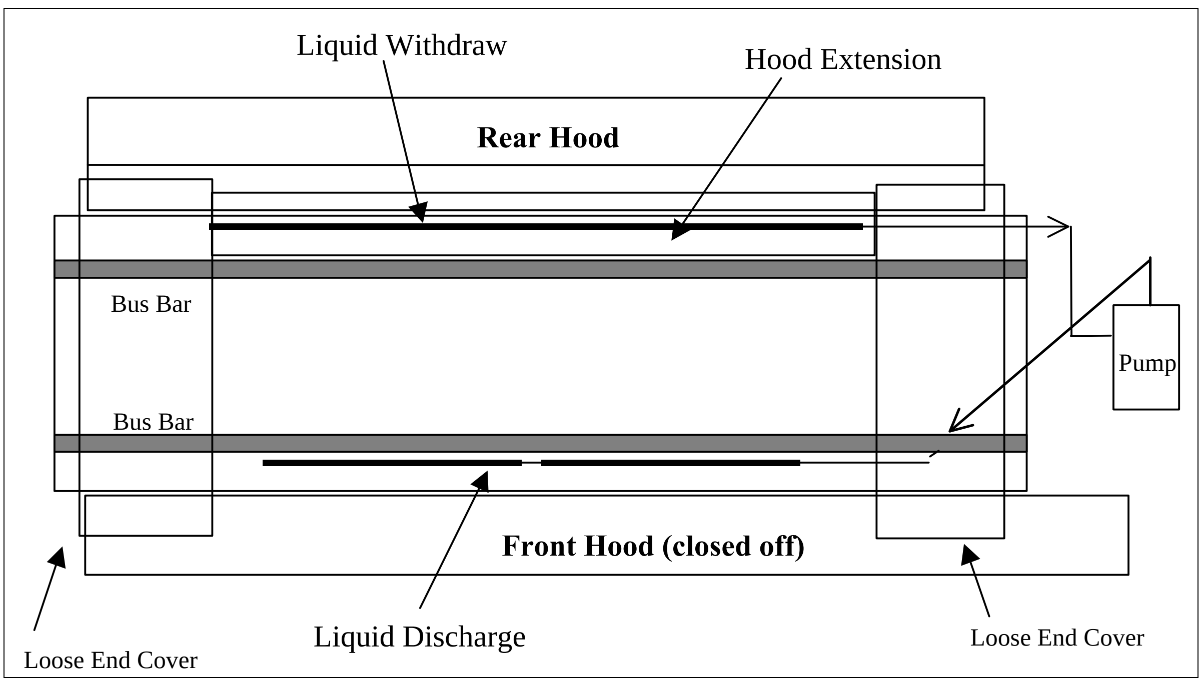

Figure 2. Top View of PLRS (not to scale)

Figure 3 shows a scaled schematic of the electroplating tank arrangement and the positioning of the PLRS in the tank at MCLB Albany during the demonstration. Sampling locations are either 20 inches above the plating solution (letters A to D, F to I, and K to N) or 48 inches above the solution (letters Q, R, and S).

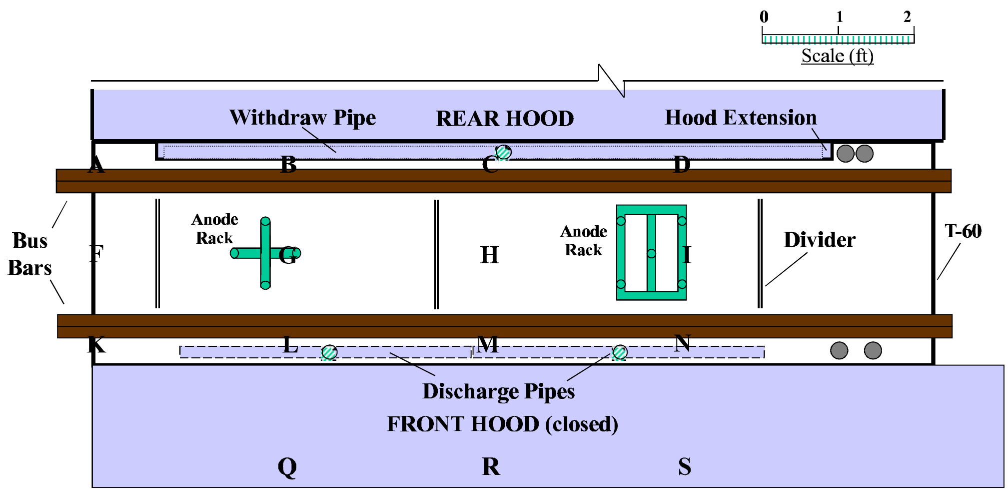

Figure 3. Top View of Plating Arrangement and Sampling Locations

A typical design air flow rate used for standard pull-pull ventilation systems for chromium electroplating is 250 standard cubic feet per minute per square foot (scfm/sf) of plating tank surface area. The goal for the PLRS technology is for a reduction to approximately 60 cfm/sf. The liquid flow should be adequate to push the liquid surface across the short side of the tank within two seconds. A general design flow rate is 3 gal/minute/sq. ft. of tank surface area.

The liquid pump was placed in the containment pit next to the tank. During the demonstration, the PLRS pump power switch was operated manually. For an actual implementation of the PLRS technology, this switch should be linked to the rectifier power switch so that the PLRS operates at all times of active electroplating. During inactive times, the PLRS would remain idle and only the ventilation system would operate. In this way, the system would be completely automated.

It is important that the tank possesses an automated level controller so that the plating liquid level is maintained within a 5 cm range during active plating because of the fixed position of the liquid return jets near the surface. The system does not operate properly if the liquid is not within this range.

During active plating, the operator should be careful not to place obstacles directly (0 to 5 cm) in front of the liquid return jets. Deflection of the plating solution coming out of the jets could occur, resulting in the spraying of solution out of the tank. A recent design modification would provide for a protective shield directly above the jets to prevent this from occurring.

Several tests of the PLRS technology were conducted at various ventilation flow rates. Each run was completed in approximately four hours. The duration of the whole demonstration was four days.

3.3 MONITORING PROCEDURES

During the demonstration, two industrial hygiene sampling techniques were used to determine hexavalent chromium emission levels from the electroplating tank. These techniques were the standard OSHA Method ID-215 (OSHA 1998) and real-time Spark-Induced Breakdown Spectroscopy (SIBS) (Fraser et al., 1998a, 1998b and 1999). SIBS allowed a detailed scan of the electroplating tank to determine the overall emission pattern during operation. It also provided quick results so modifications could be made during the demonstration. Method ID-215 is an OSHA approved method that was used to verify the SIBS measurements and to provide data to determine whether the performance objectives were met. Ventilation flow rate measurements were made using USEPA Method 2 (40CFR60A).

Quality assurance measures are described by Hay et al. (1999) and USACHPPM (1998). SIBS measurements were analyzed onsite while Method ID-215 samples were evaluated offsite by USACHPPM (1998).

Once installed, monitoring of this particular technology would not be necessary. However, typical stack emission testing as mandated by State and Federal regulations (NESHAP) must be performed to prove compliance for the control device. Industrial hygiene measurements are only necessary for in-house reasons or if OSHA suspects a violation.

3.4 ANALYTICAL PROCEDURES

As part of OSHA Method ID-215, the industrial hygiene samples were analyzed for hexavalent chromium content using an ion chromatograph as discussed in the demonstration plan (Hay, 1998a). Real-time SIBS measurements were provided by the SIBS instrument on-site. It is important to note that the SIBS measurements were averaged over approximately 3 minutes at each sampling location while the OSHA Method ID-215 samples were taken over a period of about 1 hour each. The SIBS device measures total chromium and cannot differentiate between valence species. It is assumed that a large majority of chromium emitted from the electroplating tank is in the hexavalent state so that comparisons between the ID-215 and SIBS measurements are reasonable. Detailed descriptions of the use of these methods during the demonstration are provided in the project demonstration plan (Hay, 1998a), final report (Hay et al., 1999) and Fraser et al. 1998a and 1999).

3.5 DEMONSTRATION SITE/FACILITY BACKGROUND AND CHARACTERISTICS

The Marine Corps Logistic Base in Albany, GA is a government owned/operated facility that performs vehicle rework on military vehicles. The facility generally plates small military vehicle parts such as camshafts and hydraulic shafts. The electroplating shop possesses one chromium electroplating tank with dimensions of 11 ft long by 3 ft wide by 8 ft deep, and holds approximately 2000 gal of plating solution. The largest part plated is about 3 ft long by 1 ft in diameter. The parts are plated in batch mode controlled

manually. Typically only one large part or a basket containing several small parts are plated for several hours.

The facility has a rectifier with a capacity of 8,000 amps. It has been estimated that the maximum cumulative potential rectifier capacity for the unit is 47 million ampere-hours per year (ESE, 1995) assuming 8,400 hours of operation a year with 70 percent usage of rectifier at maximum amperage. This qualifies the operation as a small hard chromium electroplating facility under the USEPA National Emission Standard for Hazardous Air Pollutants (NESHAP) (60FR4948). The actual usage of the unit is much less. Typically, the unit is operated one shift per day, 5 days per week. In addition, the unit can be operated up to a maximum amperage of 1200 amps without arcing and is usually operated near 400 amps to achieve high quality plating.

The primary appeal of performing a demonstration at MCLB Albany is that this site has only one active chromium electroplating tank. Most DoD facilities with chromium electroplating have multiple tanks. The ambient chromium concentration at MCLB Albany is solely due to this single tank (i.e., no contributions from nearby tanks). Because of the importance of industrial hygiene sampling, this site was ideal for testing the PLRS.

Like all other chromium electroplating facilities, the hexavalent chromium emissions generated by the process must be controlled to levels dictated by applicable air regulations. The existing air pollution control system includes a horizontal composite mesh pad, a horizontal fiber bed mist eliminator, and a vertical chevron mist eliminator, respectively in-series. The device includes a 15 horsepower blower motor run continuously at a rate of approximately 6750 scfm (originally rated at 8250 scfm, or 250 scfm/sf). The electroplating tank had an air circulation system prior to this demonstration, but it was inoperative and removed during the demonstration. There is no treated scrubber wastewater at this facility, because there is a closed loop rinsewater system. The existing control system at MCLB Albany was tested and determined to be compliant with Georgia State regulations (and the NESHAP) in 1995.

To successfully test the PLRS, the existing ventilation system was kept in place but modified slightly to allow for large changes in the flow rate. Using dampers, the ventilation rate at the tank was varied from 6750 scfm down to 1200 scfm.

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4.0 PERFORMANCE ASSESSMENT

The performance objectives for the PLRS were met.

Table 1 summarizes the industrial hygiene measurement data for the tank surveys (Fraser et al., 1998a). The first entry in each cell is the average SIBS concentration and the second entry, if present, is a corresponding OSHA Method ID-215 result. Table 1 also gives standard deviations, which can be large due to the non-homogeneous nature of the emissions (particulates or groups of particulates in the sample stream). The accepted detection limit of the SIBS instrument is 10mg/m^3 so that data measured below this level are reported as $<$10mg/m^3. Empty cells indicate that either no measurements were taken or that data were not valid.

Table 2 lists the SIBS data for three flow conditions during which the PLRS was turned on and off. The position G (low) is located at G but only 12 in. above the liquid surface.

Figure 4 shows the internal SIBS filter results during this demonstration plotted against the corresponding SIBS integrations. Figure 4, which covers over two orders of magnitude of chromium mass, shows an excellent correlation. Four of the five measurements are within 20 percent of the filter measurements. Fraser et al. (1998a) gives details of the SIBS evaluation.

ID-215 measurements indicated that for the ventilation rates of 2249 scfm and greater the chromium concentration in the worker breathing zone remained below the current and proposed OSHA limits. However, the average ID-215 concentration increased almost one order of magnitude from 0.039 µg/m^3 to 0.28 µg/m^3 as the ventilation rate decreased from 6830 scfm to 2249 scfm. A more than one order magnitude increase to 4.7 µg/m^3 was seen as the rate decreased further to 1493 scfm.

The test at full ventilation (6830 scfm) without the PLRS showed that the existing system was more than adequate at controlling fugitive emissions. At all sampling locations, the chromium concentration was below the SIBS detection limit. The ID-215 results were very low, even directly above the tank at position H. SIBS measurements do not indicate chromium concentrations above 10 µg/m^3 until the ventilation rate was decreased to 2249 scfm. At this rate, only two locations, B and M, had measurements above the detection limit. As the ventilation rate was decreased more, more locations had measurements above 10 µg/m^3 and the concentrations were greater. This was particularly noticeable between the two ventilation rates of 1845 scfm and 1493 scfm. During the test at 1200 scfm, a Draeger colorimetric tube test indicated a chromium concentration above the OSHA PEL in the worker breathing zone. A very high concentration is also shown by the only SIBS measurement taken at this rate. Therefore, for health and safety reasons, a full SIBS scan was not taken.

Table 1. Tank Survey Chromium Concentrations *(ID-215 and SIBS Measurements)*

Venti-lation Flow Rate, scfm	PLRS on/off	Measured Concentration (µg/m^3)														
		A	B	C	D	F	G	H	I	K	L	M	N	Q	R	S
6830	off	<10	<10	<10	<10	<10	<10	<10 0.072±0.018	<10	<10	<10	<10	<10	<10 0.054±0.038	<10 0.031±0.015	<10 0.033±0.042
4827	on					<10	<10	<10	<10							
3263	on	<10	<10	<10	<10	<10	<10	<10 0.12±0.02	<10	<10	<10	<10	<10	<10 0.045±0.017	<10 0.036±0.016	<10
2249	on	<10	25±16	<10	<10	<10	<10	10±14	<10	<10	<10	13±14	<10	<10 0.25±0.15	<10 0.28±0.14	<10 0.31±0.12
1845	on	<10	<10	11±20	72±55	<10	<10	13±10	186±50	18±12	<10	15±14	27±22	15±13	<10	13±10
1704	on	<10	<10	<10	57±37	93±70	47±41	<10	85±57	27±9	<10	36±34	69±64	14±10	11±3	16±8
1493	on	32±32	481±163	125±35	259±114	116±80	384±101	152±74 228±158	448±110	144±77	89±74	138±74	190±93	<10 4.6±0.4	17±4 4.2±1.1	16±24 5.2±1.0
1200	on											880±302				

Table 2. SIBS Data *(PLRS Off/On)*

Ventilation Rate (scfm)	Sampling Position	Avg. Conc. (µg/m^3) PLRS on	Avg. Conc (µg/m^3) PLRS off
3263	G	58±24	121±27
1845	I	165±123	259±102
1845	G (low)	576±397	1223±291

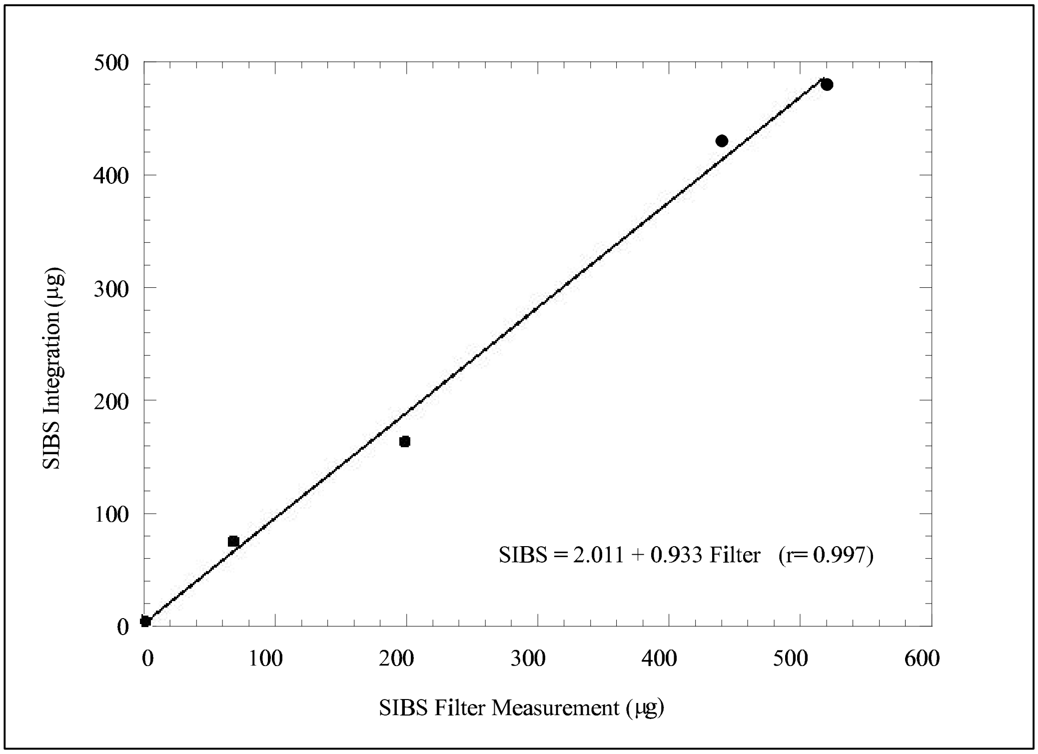

Figure 4. SIBS Filter Results Compared with SIBS Integrations

Figure 5 shows the tank survey data in Table 1 averaged for each ventilation rate (not including positions Q, R, and S). Values less than the detection limit are averaged as 10 m/cm^3, which provides an overestimated value for ambient concentrations. However, this figure gives a good indication of the effect of lowering the ventilation rate on the capture of fugitive emissions. The average ambient concentration above the tank increases at a ventilation rate of 2300 scfm. The first data points above the OSHA PEL are observed at 1845 scfm. Based on this plot, it appears a minimum design ventilation rate for this system is approximately 2500 scfm. This represents a 63 percent reduction in the current ventilation rate and a 70 percent reduction from the original design rate of 8250 scfm.

The SIBS measurements appeared to be consistent with the ID-215 method measurements. This was evident at position H. Measurements at 6830 and 3263 scfm were well below the SIBS detection limit. At 2249 scfm the ID-215 measurement is within SIBS detection. Unfortunately, a SIBS measurement was not taken at this position. However, the other measurements A through N are consistent. At 1493, the SIBS measurement of 152±74 was within range of the ID-215 measurement of 228±158, which helped to verify the accuracy of the SIBS measurements. Most SIBS measurements taken in the worker breathing zone were below the detection limit. At 1493 scfm, the SIBS measurements that were above the detection limit compare well to the ID-215 measurements.

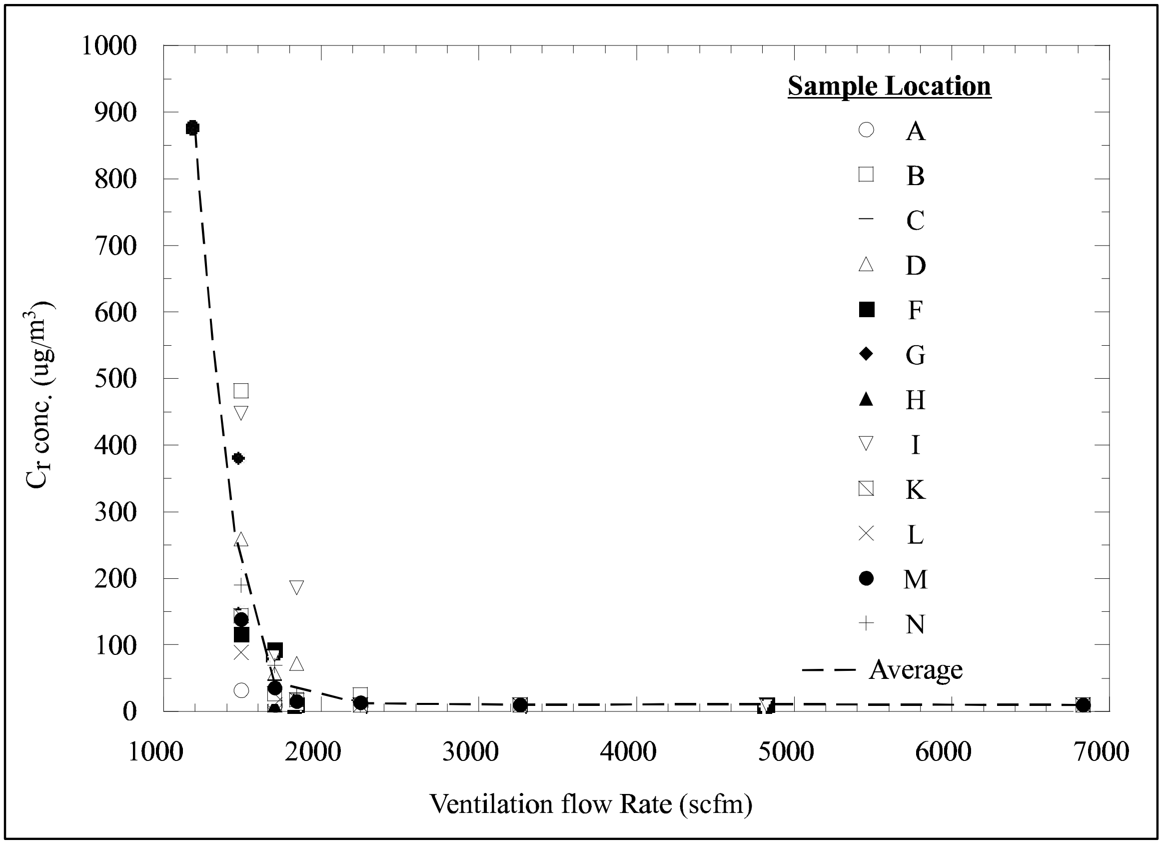

Figure 5. Concentration Above Tank vs. Ventilation Rate

Figure 6 shows the relationship of worker breathing zone concentration to the ventilation rate. It should be noted that the point on the graph corresponding to the ID-215 measurement at 3263 scfm was based on a limited number of sampling points. Only one sample was taken at each of positions Q and R, and no samples were taken at position S. However, the data shown in Figure 6 supports a minimum design ventilation rate of approximately 2500 scfm (~75 scfm/fs).

Table 2 lists some data to assess whether the PLRS is actually providing a benefit, and whether the lower ventilation rate was effective in controlling the emissions without the PLRS. The data indicate an average 47 percent reduction in emissions at the three sampling points with the PLRS operating. This is not conclusive due to limited data. However, visual observations support the measurements. It was clearly observed that the PLRS reduced the mist above the tank while operating. Figures 7a and 7b show how bubbles from the plating activity are controlled and pushed toward the ventilation hood by the PLRS.

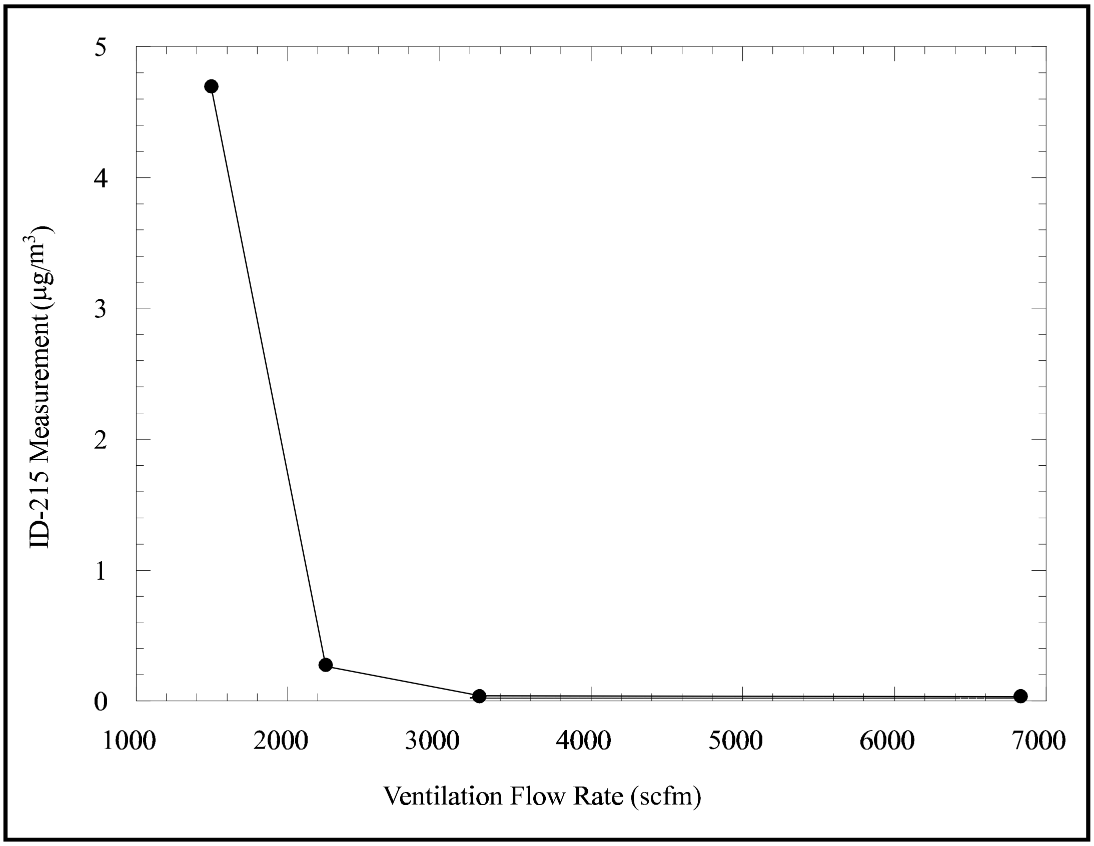

Figure 6. ID-215 Measurements vs. Ventilation Rate

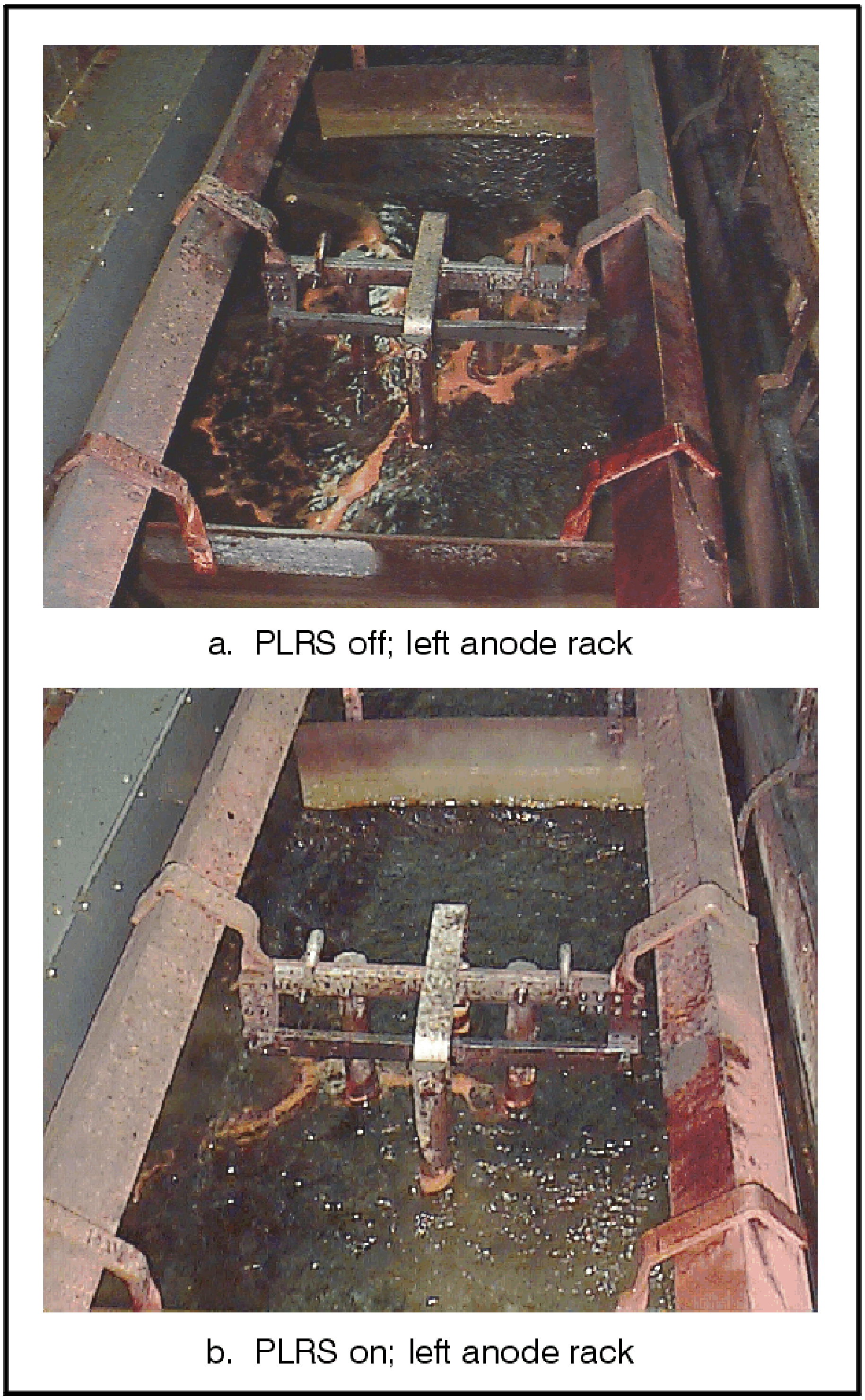

Figure 7. Effect of PLRS on Surface Bubbles (a. PLRS off, b. PLRS on)

Overall, the results of the demonstration clearly show that the ventilation rate can be safely lowered using the PLRS. The results indicate, but do not prove, that the PLRS lowers emission release above the center of tank, plating activities are not affected by the liquid cross flow, and that the SIBS technique is a useful tool for measuring chromium concentrations above an active electroplating tank. What was not shown conclusively was whether it was possible to significantly reduce the ventilation rate without the PLRS. An experiment that would have helped determine this would have been to perform an additional tank survey at each ventilation rate without the PLRS operating. This experiment was not conducted due to time restrictions during the demonstration.

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5.0 COST ASSESSMENT

Table 3 provides a comparison between the conventional technology implemented at MCLB Albany and a system utilizing the PLRS. The ventilation requirement used in Table 3 for the conventional system is 250 scfm/sf. The PLRS would decrease this requirement to 75 scfm/sf. Table 3 indicates 25 % capital savings and 48% annual savings which represents an overall lifetime savings of 38%. Note that the savings in capital costs would not be realized until a later life cycle when a smaller conventional ventilation system would be installed to replace the existing unit at the end of its regular service life.

Some annual costs are not included in Table 3. These include permitting, stack monitoring and testing, chromic acid recovery and scrubber wastewater treatment. It is assumed that these costs will be similar for both options.

At other locations with more expensive energy, the annual savings of the PLRS would be larger. In addition, reducing the ventilation in colder climates translates to less heating of indoor air during colder months. These savings can be greater than the energy savings through the reduction in the main blower size (Hankinson et al., 1998). An estimated $1 in heating bill savings is possible per cubic foot per minute reduction in the ventilation rate. If the example in Table 1 was in a cold climate, the PLRS would allow for an additional $5750 in savings.

The potential life cycle savings due to PLRS implementation at the 21 DoD facilities and approximately 1,500 commercial shops that conduct hexavalent chromium electroplating and/or anodizing operations is estimated to be over $100,000,000. This is assuming that each commercial facility has an average of two average sized tanks and the average life cycle cost per tank for conventional technology is $90,000.

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The PLRS energy savings are affected by the hours of operation because the liquid pump only operates during electroplating and the ventilation blower operates continuously. The more hours a facility operates during the day, the less the energy savings. During pump operation some of the energy reduction achieved through the lower ventilation rate will be offset.

The maintenance costs for a ventilation system using the PLRS should be comparable to that of a similar but larger control system without the PLRS. Due to its smaller size, the costs for replacing filters should be less but the additional piping and liquid pump would probably compensate for the reduction. Using a vertical, submersible pump (no seals) will minimize the maintenance requirements for the pump.

The potential life cycle savings due to PLRS implementation at the 21 DoD facilities (approximately 137 tanks) that conduct hexavalent chromium electroplating and/or anodizing operations is estimated to be approximately $5,000,000.

To install the PLRS in a permanent setting would mandate the retrofit of the existing system to a constant low flow rate. This would include the replacement of the blower and control devices. If implemented at MCLB Albany, the cost benefits at this location would primarily be a reduction in power requirements and maintenance costs. Because there is an existing device meeting current regulatory requirements, no immediate capital benefit would be realized. In fact, the capital costs for retrofitting the system would not quickly be offset by operational savings. However, when the time comes for installing new ventilation equipment and control device, integrating the PLRS into the control scheme could save capital.

6.2 PERFORMANCE OBSERVATIONS

The performance of the unit is measured in its ability to lower the ventilation requirements without allowing an increase in the ambient chromium concentration and risking the workers' safety. Factors that could affect the performance during operation include the positioning of the liquid discharge pipes under the liquid surface, large obstacles (parts, anodes, shields) that significantly interrupt the cross-flow pattern of the solution, and large room-air drafts in the plating shop. The holes in the liquid discharge pipes should be positioned no more than 2.5 in. below the surface to ensure adequate surface flow. The surface velocity will begin to quickly decrease as the holes in the pipes descend below 3 in. and splashing can occur if the jets in the pipes are at the surface or above. Thus level control is necessary in a tank using the PLRS. Large obstacles at the surface can prevent the flow of bubbles toward the ventilation hood. Room drafts, if large enough, can disrupt the ventilation pattern at the tank and push emissions into the worker breathing zone.

Table 3. Cost Comparison Between Conventional System and PLRS

	Conventional Pull System	PLRS
Specifications & Capital Costs:		
Ventilation System Flow Rate	8250 CFM	2500CFM
Ventilation Blower Size[2]	20 BHP	7.5 BHP
Auxiliary Pump Size	N/A	5BHP
Blower, Ducts, Control[1]	$37,761	$17,680
Installation of Ventilation[1]	$7,158	$6,060
Delivery of Ventilation[1]	$2,900	$2,900
Startup of Ventilation System[1]	$1,850	$1,850
Auxiliary Equipment	N/A	$4,000
Installation of Auxiliary Equipment[3]	N/A	$2,000
Design & Start-up of		
Auxiliary Equipment[4]	N/A	$2,800
Total Capital Costs	**$49,669**	**$37,290**
Annual Operating Costs:		
Required Ventilation Blower BHP	14.58	5.25
Ventilation Blower Electrical Efficiency	86%	84%
Auxiliary Pump Efficiency	-	85%
Ventilation Blower Operating Hours	8700	8700
Auxiliary Pump Operating Hours	None	1500
Electricity Cost $/kWh	$0.050	$0.050
Ventilation Blower Electricity	$5,496	$2,026
Auxiliary Equipment Costs	N/A	$329
Materials Costs	$200	$100
Operating Labor Costs	N/A	N/A
Maintenance Labor Costs	$1,000	$1,000
Total Annual Operational Cost[6,7] :	**$6,696**	**$3,455**
Operational Costs in Present Worth[6,7]	**$41,142**	**$21,230**
(10 yr., 10% interest factor is 6.1446)		
Total Costs in Present Worth[6,7]	**$90,811**	**$58,520**
(10 yr., 10% interest factor is 6.1446)		

Assumptions and notes used to create Table 3 are:

1. The cost and size of the mist eliminator, blower, ventilation ducting systems, ventilation system installation, and delivery, and also the startup costs are based on a quote from the original equipment supplier. The conventional system here includes a preliminary mesh pad unit, a horizontal composite mesh pad unit, the blower, a chevron blade mist eliminator, ductwork, and hoods.
2. The exhaust blower power requirements are based on information supplied by the blower manufacturer.
3. The auxiliary system installation costs for the PLRS are estimated at 40 hours at $50.00 per hour.
4. Auxiliary system design and startup is estimated at 40 hours at $70.00 per hour.
5. Electricity rate is based on the current annual average electricity cost at MCLB Albany, GA.
6. A 10-year life expectancy is based on the experience of MCLB Albany.
7. The annual cost dollar value will remain constant for 10 years.

6.3 REGULATORY AND OTHER ISSUES

The primary regulatory issue for this technology is the chromium concentration in the worker breathing zone (29CFR1910.94). Although no OSHA paperwork or permits are necessary to operate an alternative technology, it is important that this technology maintain the ambient concentration within specifications for worker safety. This standard can be enforced if violations are reported and substantiated.

A chromium electroplating facility must comply with applicable State and Federal requirements (USEPA NESHAP) for the employed control device. This is true whether or not the PLRS is being utilized.

6.4 LESSONS LEARNED

Several lessons were learned during the installation and operation of the PLRS during the demonstration:

Installation Parameters

1. It is important to level the liquid return pipes when installing. When properly leveled, the jets will provide an even flow across the surface.

2. The design should incorporate the sides of the tanks as barriers so that bubbles near the sides will be contained within the surface flow.

3. A protective shield should be installed directly above the jets so that an accidental blockage will not cause spraying of plating solution upwards and out of the tank.

Operational Parameters

Observations made during the demonstration led to the following design improvements (yet to be tested):

- The pump used for the PLRS demonstration was the same 7.5 horsepower pump originally supplied with the VVST. Since liquid only needs to recirculate from one side of the tank to the other, a vertical, submersible pump with its head piped and submerged in the plating solution would be more cost effective (because a smaller pump motor could be used). Savings would include the capital costs of piping, pump and installation labor, pump maintenance (no seals to replace), and energy costs (lower horsepower required). Eliminating the external pump would also keep the electroplating solution within the tank.

- The modified hood design should extend over the entire side of the tank so that the side tank walls can be used as barriers to contain any fugitive emissions. This would also eliminate the need for partial tank lids.

- The liquid discharge pipes should be secured and level. Also, the piping arrangement should provide even flow to each discharge pipe.

It is expected that this technology could allow for a reduction to approximately 60 scfm/sf if the improvements listed above are implemented.

6.5 SCALE-UP

The device was tested in a full-scale tank. Adjusting to a larger facility will involve installing an additional PLRS unit for each tank. Since multiple tanks may exist on one ventilation system, a new ventilation rate should account for the ventilation reduction contributions from all of the tanks. It is estimated that cost reduction percentages will be fairly constant regardless of facility size.

7.0 REFERENCES

Key References

1. Hay, K.J., *Venturi/Vortex Scrubber for Controlling/Recycling Chromium Electroplating Emissions*, ESTCP Project Demonstration Plan (modified), U.S. Army Construction Engineering Laboratories, February 1998(a).

2. Hay, K. J., S. Qi, J. I. Northrup, S. R. Heck, *Development of Venturi/Vortex Scrubber Technology for Controlling Chromium Electroplating Hazardous Air Emissions*, Technical Report 98/40, U. S. Army Construction Engineering Research Laboratories (CERL), July 1998(b).

3. Hay, K.J., S. Qi, B. Holden, N. Helgeson, M. E. Fraser, G. Braybrooke, *Venturi/Vortex Scrubber Technology for Controlling/Recycling Chromium Electroplating Emissions*, ESTCP Demonstration Project Final Report, Technical Report 99/43, U.S. Army Construction Engineering Research Laboratory (CERL), March 1999.

4. Ferguson, T. D., "Use of Mist Suppressants in Hard Chrome Electroplating", *Plating and Surface Finishing*, 86, 6, 76-80 (1998).

5. Code of Federal Regulations (CFR), title 29, part 1910, section 94.

6. Altmayer, F., *Plating and Surface Finishing*, 83, 6, 35-37 (1996).

7. OSHA, *Hexavalent Chromium in Workplace Atmospheres*, OSHA Method Number ID-215, 1998.

8. Fraser, M. E., T. Panagiotou, A. J. R. Hunter, E. B. Anderson, S. J. Davis, G. Braybrooke, and K. J. Hay, "Fugitive Emission Measurements Above a Hard Chromium Plating Tank Using Spark-Induced Breakdown Spectroscopy (SIBS)," submitted to *Plating and Surface Finishing*, 1998(a).

9. Fraser, M. E., A. J. R. Hunter, S. J. Davis, and K. W. Holtzclaw, "Spark-induced Breakdown Spectroscopy (SIBS) - A New Technique for Monitoring Airborne Heavy Metals," submitted to *Appl. Spectrosc*. 1998(b).

10. Fraser, M.E., T. Panagiotou, A. J. R. Hunter, G. Braybrooke, and K. J. Hay, *"Fugitive Emission Reduction and Measurement Above a Hard Chromium Plating Tank." Proceedings of the 20th AESF/EPA Conference for Environmental Excellence,"* Orlando, Florida, January 1999.

11. Environmental Science & Engineering, Inc. *Emission Test Report for Marine Corps Logistics Base Chrome Plating Facility Albany, Georgia*. ESE No. 3195694G-0100-3100, 31 October 1995.

12. Federal Register (FR), vol. 60, p. 4948 (1995).

13. Hankinson, K. C., T. Brady, A. Chmielewski, "Considerations for Total Pollution Control: Energy Conservation and Process Control Utilizing Covered Tanks," KCH Services (1998).

14. Code of Federal Regulations (CFR), title 40, part 60A.

Laboratory Data Reference

1. U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM), *Final Report, Industrial Hygiene Survey No. 55-ML-6906-98, Chromium Electroplating Emissions testing, U. S. Marine Corps Logistics Base Albany, Georgia*, 14-17 April 1998, September 1998.

General References

1. Hay, K. J., J. Northrup, S. R. Heck, "Venturi/Vortex Technology for Controlling Chromium Electroplating Emissions," *Proceedings for Air & Waste Management Association's 90th Annual Meeting*, Toronto, Canada, 1997.

2. Castle, R., U. S. Patent 5,149,411 (1992).

3. Hunter, A. J. R., J. R. Morency, C. L. Senior, S. J. Davis, and M. E. Fraser, "Continuous Emissions Monitoring Using Spark-Induced Breakdown Spectroscopy (SIBS)", submitted to *Env. Sci. Technol.* (1998).

4. USEPA, *Technical Assessment of New Emission Control Technologies Used in the Hard Chromium Electroplating Industry*, 453/R-93-031, July 1993.

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